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SHORT COMMUNICATION

Osteophagia of sea turtle bones by white-tailed deer (*Odocoileus virginianus*) in Santa Rosa National Park, northwestern Costa Rica

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Abstract

Herbivores obtain nutrients mostly from the vegetation they consume, but may obtain additional minerals during periods of nutritional stress by consuming bones (osteophagia), a behavioral strategy that has been reported for many wild ungulate species, including the white-tailed deer (*Odocoileus virginianus*). Here we document multiple records (n = 183 camera-trap records) of osteophagia by white-tailed deer chewing sea turtle remains (resulting from jaguar [*Panthera onca*] predation) near a nesting beach in Santa Rosa National Park, Costa Rica during January-September 2017. Females with fawns, males with hard and velvet-covered antlers, and non-spotted fawns reached a peak of sea turtle bone consumption during June to August. We hypothesize that seasonality, sex, age, and individual growth stage influence the frequency of osteophagy as a strategy to cope with environmental changes and food resource scarcity. Finally, these observations highlight the role of an apex predator as indirectly influencing rare but important ecological processes.

Keywords

bone chewing, diet, dry forest, food web, minerals, nutrients, ungulate

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PENSOFT

The white-tailed deer (*Odocoileus virginianus*), a medium-size ungulate distributed from Canada to Bolivia (Gallina and Lopez-Arevalo 2016; Gallina et al. 2019), is an herbivorous ruminant browser, feeding mostly on leaves, twigs, sprouts, shrubs, and fruits (Gallina et al. 2010; Jara-Guerrero et al. 2018). In the tropics, this deer species is considered an opportunistic concentrate feeder (Gallina et al. 2010) that selects forest patches or areas with abundant and high-quality vegetation (López-Pérez et al. 2012), but whose diet and habitat selections change with seasons. As a consequence, there may be times when deer and other ungulate species need minerals and substances in the environment that perform as regulators to detoxify secondary compounds contained in some shrub species (Campbell and Hewitt 2004). In addition, minerals are essential to maintain proper growth, reproduction, and health through the individual life stages (Carrillo-Sánchez 2020). Since these cannot be synthesized, they are sometimes obtained from other sources such as freshwater, mineral rocks and soil, or salty water near coasts (Campbell and Hewitt 2004; Ramírez-Lozano 2012; Rodríguez 2015).

For ungulates, another tactic used to obtain additional mineral nutrients is chewing antlers or bones, a behavior known as osteophagia. There are numerous previous reports of osteophagy in herbivores in general (see Cáceres et al. 2011), in African ungulates (in Langman 1978; Hutson et al. 2013), and in Nearctic and Palearctic cervids (in Bowyer 1983; Gambín et al. 2017), including mule deer (*Odocoileus hemoinius*; Krausman and Bissonette 1977) and white-tailed deer (Meckel et al. 2018). This feeding behavior is ascribed to a nutrient-deficient environment where there is a need to obtain minerals, particularly phosphorus and calcium, lacking in their diet (Browthwell 1976; Sutcliffe 1977; Keating 1990; Hutson et al. 2013; Meckel et al. 2018). Previous evidence of osteophagia indicated seasonality related to vegetation changes, age stages, and reproduction as triggers of this behavior (Gambín et al. 2017; Meckel et al. 2018). Here we document osteophagia by white-tailed deer on carcasses of nesting olive ridley (*Lepidochelis olivacea*) and green sea turtles (*Chelonia mydas*) killed and first fed on by jaguars (*Panthera onca*) (Fig. 1A) on a beach in the dry forests of northwestern Costa Rica. Additionally, we highlight monthly differences related to sex and reproductive status of osteophagic deer to help identify potential factors influencing the behavior.

Our observations were made in Santa Rosa National Park (SRNP) in the Área de Conservación Guanacaste (ACG), located in northwest Costa Rica (10°50'47"N, 85°40'21"W) and an area that is a recovering lowland seasonal dry forest (Janzen and Hallwachs 2016; Jimenez et al. 2016). Average annual rainfall of 1,600 mm is highly seasonal (mo. ave.: 0–1,040 mm); the wet season (months with ≥ 40 mm of rain) is May to November, and the dry season (with almost no rain and temperatures over 37 °C) is December to April. The white-tailed deer is a common species (Fuller et al. 2020), and on the Naranjo and Nancite beaches jaguars regularly kill off olive ridley (*Lepidochelys olivacea*) and green (*Chelonia. mydas*) sea turtles that exhibit year-round but seasonal solitary nesting (Montalvo et al. 2020).

Our observations arise from a single camera trap in Tule beach (10°48'36"N, 85°42'42"W), 1.1 km northwestern from Nancite Beach, operating from 14 January–8 September 2017 near a mangrove zone in a place known for a concentration of sea turtle carcasses that were the remains of jaguar kills. It was one of an array of cameras designed to maximize photo captures of jaguars and their prey over an area of ~100 km^2 (Fuller et al. 2020; Montalvo et al. 2020).

To quantify rates of osteophagia, we considered photo events as independent if they were taken at least 30 minutes apart. We used physical characteristics and size comparisons to segregate white-tailed deer by sex and age (Fuller et al. 2020). A full-sized individual was considered an adult male if genitalia or antlers were visible. Antlers were categorized as "nubs" (visible pedicels), "velvet" (growing antlers with velvet and rounded tine ends), and "hard" (fully formed antlers). Adult individuals with no observable antlers or genitalia were classified as females in two categories: "solitary" and "with fawns". Deer fawns were identified by their body size and categorized as "spotted" and "non-spotted". To evaluate statistical evidence of monthly differences in the frequency of independent photo records we used a Chi-square test using the statistical software R version 4.1.1 (R Core Team 2021).

With a total effort of 237 trap nights from a single camera, we recorded 463 independent photo events of white-tailed deer (Fig. 1B, C). Of these, 183 (39%) documented white-tailed deer chewing sea turtle bones (females; n = 81, males; n = 77, fawns; n = 25). Although no monthly variation in photo rates of osteophagia was identified for adult males with nubs (p = 0.53; Table 1) or spotted fawns (p = 0.64), adult females, both solitary and when with fawns, had the highest frequency of chewing sea turtle bones during July ($p < 0.02$), adult males with hard and velvet antlers in June-July and August ($p < 0.01$), and non-spotted fawns in July and August ($p < 0.01$).

Based on these field observations, osteophagia by white-tailed deer on sea turtle bones seems a common behavior near nesting beaches where jaguars prey on sea turtles. As with ungulates elsewhere, this behavior likely provides minerals such as calcium, sodium, and phosphorus that have been identified as bone-builders, and regulate the nerve impulses, contraction, and relaxation of blood vessels, also

Table 1. Monthly number of independent photo records (n = 183) of sea turtle osteophagy for different categories of white-tailed deer (*Odocoileus virginianus*), collected during January-September 2017 in Santa Rosa National Park in northwest Costa Rica.

Category		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	X^2	P value
Adult female (by reproductive status)	With fawns	0	0	1	4	3	4	12	6	1	33.74	< 0.01
	Alone	1	3	8	5	7	9	10	7	0	18.04	0.02
Adult male (by antler growth stage)	Nubs	1	1	3	3	1	2	5	2	1	7.05	0.53
	Hard	0	3	4	0	0	6	5	7	0	23.6	< 0.01
	Velvet	0	0	2	6	5	9	9	2	0	30.0	< 0.01
Fawn (by age)	Spotted	0	0	0	1	1	0	1	0	0	6.0	0.64
	Non-spotted	0	0	1	1	2	4	6	7	1	22.18	< 0.01

Figure 1. White-tailed deer (*Odocoileus virginianus*) osteophagy of sea turtle bones from turtles previously predated by jaguars (*Panthera onca*) near nesting beaches in Santa Rosa National Park, northwestern Costa Rica. A) Jaguar dragging a sea turtle; B, C) White-tailed deer chewing sea turtle bones.

controlling enzymes that inhibit blood clotting (Denton et al. 1986). Deficiencies of these minerals in ungulate species can lead to weight loss, body growth reduction, bone malformations, appetite loss, as well as decreasing the plasma volume (Carrillo-Sánchez 2020). Previous studies identified bone chewing behavior in cervids as related to lactation in females, late growth of deer fawns, the end of gestation, seasonal variations in plant minerals (e.g., African savannas, tropical dry forests), and successful antler development (Bowyer 1983; Denton et al. 1986; Estevez et al. 2010; Gambín et al. 2017). Our findings indicate that during June-August, the peak of bone chewing for females accompanied by fawns, likely helps to recover nutritional condition after gestation and during lactation at the beginning of the wet season in SRNP (Fuller et al. 2020). Solitary non-spotted fawns showed the same patterns as females, hence weaned fawns may take the advantage of getting additional calcium and phosphorus to maximize growth (Gambín et al. 2017; Fuller et al. 2020). Males with hard and velvet antlers showed differential use of sea turtle bones, aggregating their visits during the same months as solitary non-spotted fawns and females accompanied with fawns. For male deer with velvet antlers (the growth stage before the antler mineralization), the physiological demand of calcium and phosphorus increases (Denton et al. 1986).

In seasonal dry forests during long periods with no rain, a variety of animal species show different adaptations to cope with changes in vegetation (Klemens et al. 2011). Most white-tailed deer in northwestern Costa Rica probably maximize reproductive output by gaining nutritional condition during the wet season and having fawns during the beginning of the dry season when some new leaf production occurs (Fuller et al. 2020). During the dry season, fruit is on the ground and likely

some is consumed by deer (Janzen 1983; Herrera 1989), and year-round evergreen vegetation is available. Overall, the combination of the deer's reproductive stage and nutrient composition of vegetation may spur seasonal osteophagy by both males and females.

We also note the importance of the role of jaguars as a top predator supplying carcasses to other terrestrial organisms near nesting beaches (Escobar-Lasso et al. 2016), including white-tailed deer. Our observations of osteophagia by white-tailed deer on sea turtle bones indicate that seasonality, age, sex, and individual growth stage influence the frequency of this event, and also demonstrate the cascade effect of a top predator making marine biomass available to multiple terrestrial organisms.

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